Surf Zone Technology Standoff Delivery Algorithm Development

Anthony D. Jones
Cheryl M. Smith
Science, Technology, Analysis, and Special Operations Department,
Naval Surface Warfare Center, Dahlgren Division, Coastal Systems Station,
Panama City, Florida 32407-7001
Phone: (850) 234-4047 Fax: (850) 235-5374 E-mail: JonesAD@ncsc.navy.mil
http://www.ncsc.navy.mil/

Joseph W. Foster
Donna Foster
Computer Sciences Corporation, Shalimar, Florida
Phone: (850) 796-3912 Fax: (850) 651-1108 E-mail: fostersail1@yahoo.com

Document #: N0001400WX20025

LONG-TERM GOALS

The long-term goal for this project is to develop precision-guided munitions for breaching obstacles placed in the surf zone. Due to the relatively small scale of the intended targets, precise target location in global coordinates may be unavailable. A terminal guidance imaging system provided with reconnaissance images could be used to refine target locations.

OBJECTIVES

Our final objective is to develop algorithms to terminally guide a sequence of smart munitions with a high degree of accuracy to an array of obstacles placed in the surf zone. This will require a set of pre-mission algorithms to process reconnaissance images and allow an operator to define targets. On-board algorithms must then process images collected in real-time and compare them with the reconnaissance information. Toward this end there were two objectives for the FY00 software effort.

First was to investigate candidate algorithms using available data. As most tracking algorithms focus on the fixed observer/moving target scenario, open literature searches have been of little value for this problem. Algorithms for this purpose must be either adapted from other military applications or invented. The second objective was to support the sensor evaluation effort. As the algorithm performance is directly linked to image quality, it is important that candidate sensors provide the type of target information likely to be required by the algorithm.

APPROACH

We have taken a dual approach for the terminal guidance algorithm development. CSS personnel, Cheryl Smith and Abinash Dubey, are adapting an algorithm developed at the Naval Air Warfare Center Weapons Division in China Lake for Land-attack Multisensor Correlation (LMC) as part of the Air-Launched Weaponry Block program to the surf zone (small target) problem. The LMC algorithm is a straightforward approach using direct correlation between a template created using reconnaissance data and one created on the fly [1]. For the sensor selection process, images collected using candidate sensors were evaluated for their ability to produce useful templates. Edge strengths and contrast between typical targets and the background scenery were measured.

In a parallel effort, correlation algorithms are being developed and tested by Joseph Foster and Donna Foster of Computer Sciences Corporation (CSC). The CSC approach was to first identify the requirements for meeting the surf zone clearance mission. Prospective image processing techniques were then identified, prototyped, implemented in software and tested against synthetically generated surf zone imagery.

WORK COMPLETED

A reduced version of the LMC algorithm has been implemented for static images in the Advanced Visual Systems (AVS) image processing laboratory environment. This version includes a pre-mission template creator, image search, and template correlation. It has been applied to images collected by the Coastal Beach Reconnaissance Analysis Advanced Technology Development (COBRA-ATD).

The focus of the LMC approach is to minimize on-board computing requirements in favor of careful creation of a target region template pre-mission. The pre-mission template must be complex enough to be assured of only matching well with the true target. Also, it may not contain lines unlikely to be detected by the vehicle sensor: for example, shadow edges, painted lines, or edges of objects likely to be moved. The template is created by applying an orientation independent edge detector to images collected by a reconnaissance vehicle, editing sensor-dependent lines, filling any line gaps, and thinning the resulting lines to one pixel wide.

This near-perfect template is provided to the bomb's processor who corrects the template orientation and scale using heading and altitude data. Note that the only template manipulation performed on board the vehicle is a perspective transformation. Vehicle images are collected, a simple edge detection is performed, the field of view (FOV) is scanned, and an unsophisticated correlation calculation is used to find a match with the template. Once a correlation peak is detected a new process spawns to track that position as the vehicle approaches. Meanwhile the broader area scan continues in hopes of a better match. This multiple hypothesis approach keeps the algorithm from becoming fixated on a spurious match that may not correlate well with the next refresh.

For the CSC algorithm development, a baseline configuration of the munitions was established which could be used as a basis for algorithm development. Quantitatively the goal is to terminally guide a sequence of smart munitions to an array of obstacles placed in the surf zone with an accuracy of three meters circular error probable (CEP), a trajectory of near vertical, a terminal closing speed of 1000 feet/sec, and a pitch over altitude of 835 meters. Ideally, the surf zone clearance mission would be conducted at pre-dawn hours approaching from the ocean side of the surf zone. The munition to be used for this mission would nominally provide an inertial guidance accuracy of 10 meters CEP (INS/GPS), an estimated range to the target area, a closing speed and a closing vector. Surveillance imagery will be used to determine desired impact points and for development of a surf zone template.

Several challenges have been identified that could effect the performance of the target-zone tracking algorithms. The impact from the first munition will create a dust cloud that obscures the target area thus timing of the subsequent munitions must be carefully considered. The high terminal velocities of the approaching munitions will limit the processing time available to conduct aimpoint corrections.

Lastly, each munition impact will alter the scene relative to the initial template thus requiring modification/updates to the template or development of alternative techniques to fine-tune the aim-point selection process.

Several image processing algorithms have been identified as candidates and preliminary tests have been conducted on Fast Fourier Transform (FFT) related algorithms. In each case, the position and size of correlation and impact windows are assigned to the reconnaissance imagery. The correlation windows are placed in areas of the scene that are predicated to have minimum damage due to the incoming munitions. The imagery is then pre-warped to conform to the estimated sensor configuration and altitude at pitch-over as shown in Figure 1. A set of routines was developed to extract the required correlation windows from both the real-time and template imagery and perform FFT processing. These functions were carried out using a CSC-developed object-oriented image processing tool called MACET that is based on a commercially available software package called Khoros.

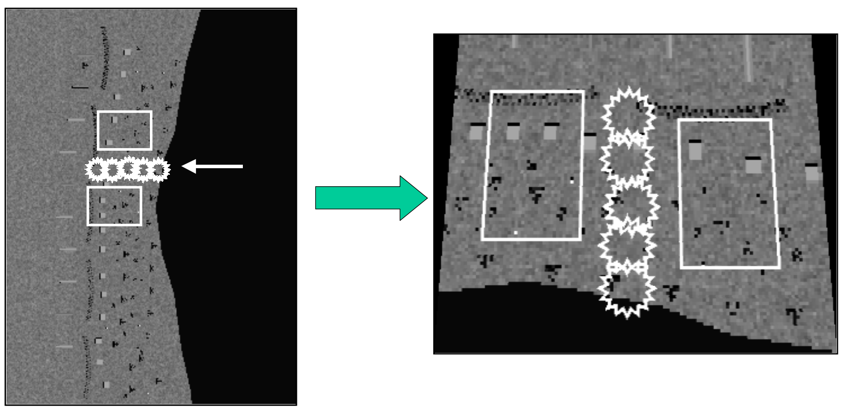


Figure 1. Assignment of correlation and impact windows to surveillance template during preplanning.

A second set of correlation algorithms is currently being developed and will be evaluated for detecting the areas of maximum change within the scene due to successive impacts by munitions. The outputs of these "target-differencing" algorithms would be used to sequentially shift the aimpoints of subsequent munitions based on the damage from previous munitions. Thus, a series of munitions could inscribe a path through the obstructions more efficiently than CEP-based munitions, resulting in lower total expenditures.

For the sensor selection effort, a preliminary test of several candidate sensors was performed [2]. Images captured in this test were statistically analyzed for edge strength and contrast between typical targets and background scenery. Each image was divided into regions containing beach, water, and a collection of barriers: concrete block, wooden post, land mines, hedgehogs, and tetrahedrons. Each region was measured for pixel intensity level and intensity variation. Also, an edge map was created for each image and the edge quality for all objects of interest was measured.

RESULTS

Results of applying the simplified LMC algorithm to images collected by COBRA-ATD's multispectral sensor are promising. The technique gave consistent results over images collected in six different bands of the visible to near infrared spectrum. Also, tests for robustness to heading measurement error showed little degradation in performance even with a 20-degree rotational error. The images in Figure 2 show the output of the algorithm applied to a COBRA-ATD image and the template used. Here template edges were detected using the SUSAN edge detector, an orientation free algorithm, and no gap filling or thinning was performed. The template image was processed to remove shadow information; the full image was not. Due to the redundant nature of the input image a relatively large template was used. Matching locations are marked with a red X.

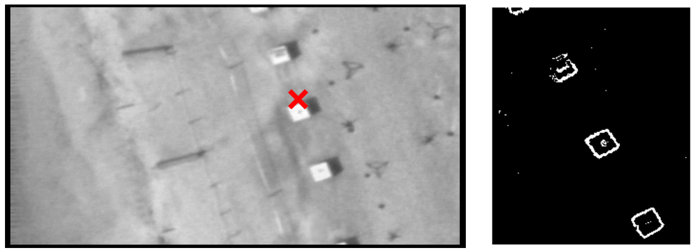
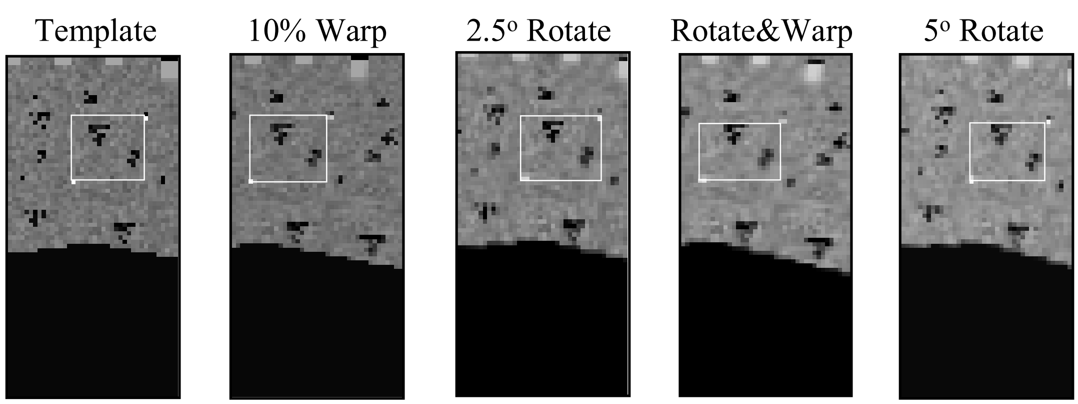


Figure 2. LMC Template Correlation Results

Correlation tests were also conducted to evaluate the sensitivity of the CSC developed algorithms to translational and rotational errors between the real-time and template correlation windows. Using synthetic imagery, tests were conducted where the template was warped, rotated, and offset-rotated to varying degrees. The results of these tests are presented in Table 1. Additional tests are currently underway where the template image will be varied in contrast, brightness, and focus.

Table 1. Correlation test results.

Template	Algorithm Results		Manual Results		Error (pixels)		Error (meters)	
	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.
Same Image	0	0	0	0	0	0	0	0
10% warp in width	9	0	11	0	2	0	0.5	0
2.5^{o} Rotate	0	3	0	0	0	-3	0	-0.75
2.5^{o} Rotate & 10% Warp	9	3	10	0	1	-3	0.25	-0.75
5^{o} Rotate	0	5	-1	1	-1	-4	-0.25	-1
2.5^{o} Offset Rotate	0	3	0	7	0	4	0	1



In support of the sensor selection effort, we compared the output from three cameras: an uncooled near/short-wave infrared (SWIR) camera from Sensors Unlimited, a cooled high sensitivity experimental SWIR camera from Sensors Unlimited, and a visible black & white camera from PULNiX. They were compared under nighttime and early morning conditions [2]. The nighttime performance for both the black & white camera and the SWIR were so poor as to make image segmentation for analysis of the various objects a challenge. In contrast the figure below shows an image collected at 2:33 AM with the experimental SWIR and its accompanying edge map. With the exception of the top of the concrete block all targets maintained good contrast with the beach throughout the night. Note that the water's edge, the posts, the concrete block with its shadow, and a small mine in the right lower corner are all clearly outlined.

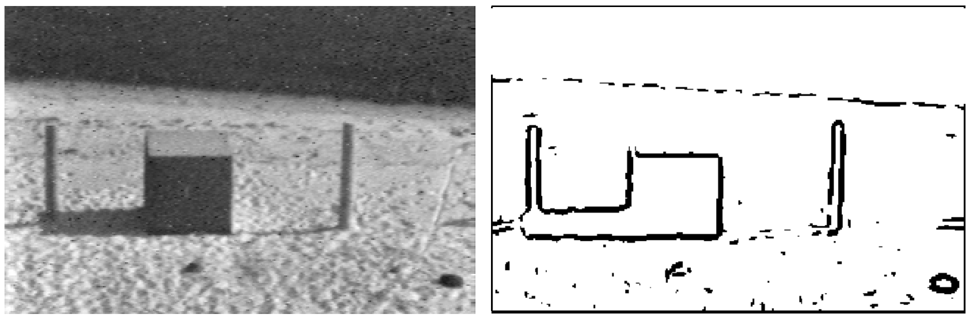


Figure 3. Experimental SWIR Image at 2:33am with Edgemap

IMPACT/APPLICATIONS

Both the preliminary camera tests and laboratory tests of possible algorithms indicate a strong likelihood for a successful outcome for this project. Multiple candidate terminal guidance algorithms have already shown promise. Finally the camera tests have demonstrated the availability of sensors capable of producing the required imagery. The guidance algorithms are potentially applicable to other military or commercial tasks that involve machine vision and where image information from a moving observer closing on a stationary target is available.

TRANSITIONS

This project will continue into FY01.

RELATED PROJECTS

This project is directly related to the Surf Zone Technology Camera Tests and Modeling project concurrently being conducted to investigate potential sensors for an image-guided seeker.

The Direct Attack Munition Affordable Seeker (DAMASK) being developed at the Naval Air Warfare Center Weapons Division uses image guidance for improved precision bombing.

REFERENCES

[1] W. Ditzler, M. Boyd, T. Corcoran, M. Franklin, J. McKnight, H. Ottenhoff, R. Tyhurst, M. Wirtz, 1995. Multispectral Image Correlation for Air-to-ground Targeting, *AGARD Conference Proceedings 563: Low-Level and NAP-of-the-Earth Night Operations*, January. (Presented at Mission Systems Panel Symposium in Italy October 1994.)

[2] A.D. Jones, 2000. Surf Zone Technology Standoff Delivery Camera Test Report (U), NSWCDD Technical Report CSS/TR-00/15, August, submitted, UNCLASSIFIED.